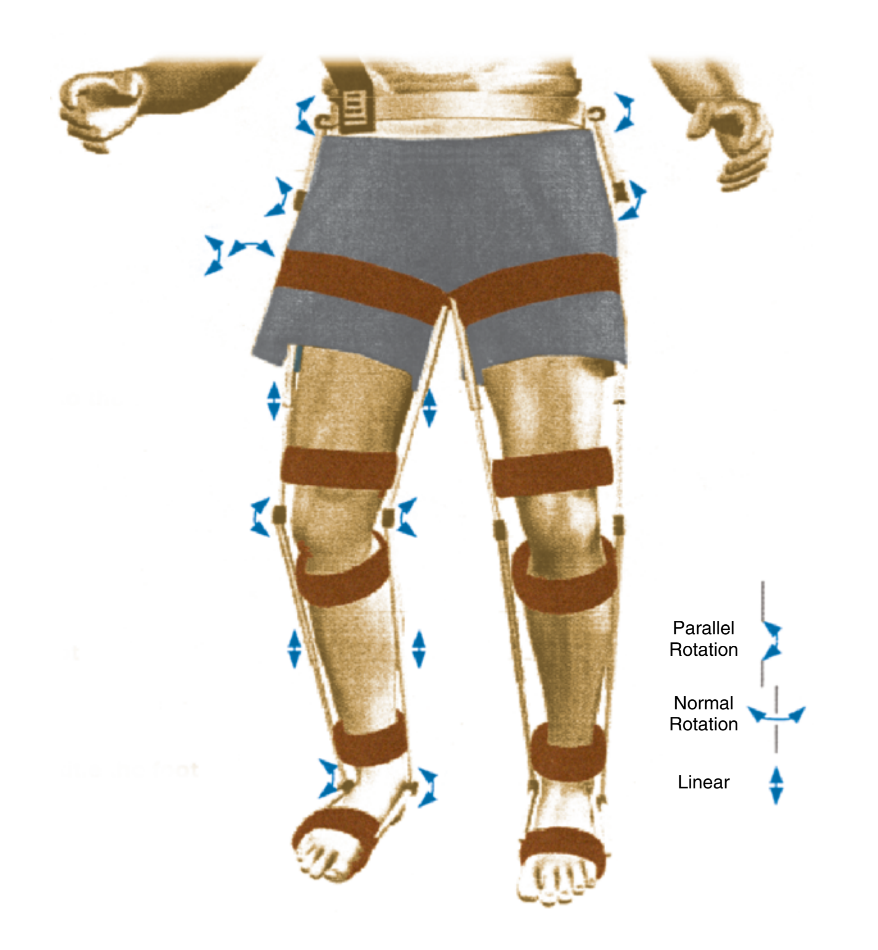
Lightweight Exoskeletons With Controllable Actuators

Resistive or assistive forces and torques would be generated on command.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed class of lightweight exoskeletal electromechanical systems would include electrically controllable actuators that would generate torques and forces that, depending on specific applications, would resist and/or assist wearers' movements. The proposed systems would be successors to relatively heavy, bulky, and less capable human-strength-amplifying exoskeletal electromechanical systems that have been subjects of research during the past four decades. The proposed systems could be useful in diverse applications in which there are needs for systems that could be donned or doffed easily, that would exert little effect when idle, and that could be activated on demand: examples of such applications include (1) providing controlled movement and/or resistance to movement for physical exercise and (2) augmenting wearers' strengths in the performance of military, law-enforcement, and industrial tasks.

An exoskeleton according to the proposal would include adjustable lightweight graphite/epoxy struts and would be attached to the wearer's body by belts made of hook-and-pile mate-rial (see figure). At selected rotary and linear joints, the exoskeleton would be fitted, variously, with lightweight, low-power-consumption rotary and linear brakes, clutches, and motors. The exoskeleton would also be equipped with electronic circuitry for monitoring, control, and possibly communication with external electronic circuits that would perform additional monitoring and control functions.



An **Exoskeleton** could be attached to a whole human body or, as in this example, to part of the body to provide exercise or assistance in motions that involve selected joints.

The linear motors could be lightweight actuators that move in the manner of an inchworm. The rotary motor actuators could be fairly conventional rotary motors, possibly equipped with clutches. Each brake or clutch would be, essentially, a rotary or linear dashpot of advanced design, containing an electrorheological fluid. (A typical electrorheological fluid is a dielectric fluid containing suspended microscopic dielectric particles. The viscosity of the fluid increases with applied electric field, with a typical response time of the order of milliseconds.) Within each brake or clutch, electrodes and flow channels would be sized, shaped, and placed so that in the absence of applied voltage, there would be minimal resistance to the affected linear or rotary motion, while at the maximum applied voltage, the actuator would resist the motion with a required force or torque, respectively. Because very little power is consumed in applying an electric field to an electrorheological liquid, a system according to the proposal used only for controlled-resistance exercise would consume little power and, hence, could be powered by a small, lightweight battery.

The electronic circuitry of the exoskeleton would include a Pentium (or equivalent) digital processor, digital-to-analog and analog-to-digital converter circuit boards, motion-control circuits, sensor-interface circuit boards, and a modem circuit card for radio communication with a remote control station. A small display device would present data on required and performed physical activity. Most of this circuitry could be mounted in a backpack.

Miniature position sensors would be placed on the joints of the exoskeleton. Miniature force and touch sensors and myoelectric or myopneumatic sensors would be placed on the wearer's body to measure flexion and extension of muscles. The sensor and control circuitry would be designed to act together to enable the wearer to act intuitively in controlling the exoskeleton. The software in the microprocessor would (1) take account of all sensor signals to infer the motion of, and the forces and torques exerted by and on, the wearer and (2) generate commands to assist or resist the wearer's motion as needed. The sensor and control design would be characterized by redundancy and robustness.

This work was done by Yoseph Bar-Cohen, Constantinos Mavrodis, Juan Melli-Huber, and Avi (Alan) Fisch of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).* *NPO-30558*

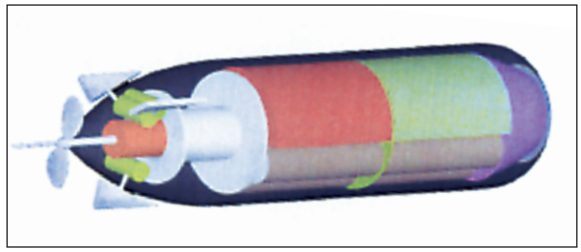
Miniature Robotic Submarine for Exploring Harsh Environments

Extreme miniaturization would enable exploration of previously inaccessible regions.

NASA's Jet Propulsion Laboratory, Pasadena, California

The miniature autonomous submersible explorer (MASE) has been proposed as a means of scientific exploration — especially, looking for signs of life — in harsh, relatively inaccessible underwater environments. Basically, the MASE would be a small instrumented robotic submarine (see figure) that could launch itself or could be launched from another vehicle. Examples of environments that might be explored by use of the MASE include subglacial lakes, deep-ocean hydrothermal vents, acidic or alkaline lakes, brine lenses in permafrost, and ocean regions under Antarctic ice shelves.

The instrumentation carried aboard the MASE would include one or more high-resolution video camera(s), circuitry for capturing image data from the cameras, and microelectromechanical-systems-based (MEMS-based) sensors designed to gather scientific data under the extreme conditions (e.g., high pressure, high or low temperature, acidity or alkalinity) of the aqueous environment to be explored. The instrumentation would be contained in easily interchangeable modules. The MASE would be equipped for autonomous control, real-time processing of scientific data, and high-speed, full-duplex communication with a monitoring station via a fiber-optic tether.



The **MASE** would be 20 cm long and 5 cm in diameter — small enough to be carried aboard another vehicle prior and to explore confined spaces inaccessible to larger exploratory vehicles.

The basic MASE concept allows for variations for different applications. In most applications now envisioned, the MASE would be designed as a disposable system to be used once.

This work was done by Alberto Behar, Fredrik Bruhn, and Frank Carsey of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1). NPO-40501*